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MINERAL FERTILIZERS' INFLUENCE ON RICE PRODUCTIVITY IN SALINE SOILS IN KYZYLORDA REGION - KAZAKHSTAN

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SUMMARY

The goal-directed study sought to determine the effects of mineral fertilizers on the productivity of two rice cultivars in the Kyzylorda region, Kazakhstan. In 2015, with the constant flooding of rice crops, the growing of two rice cultivars (Anait - a Russian breed, and Tugusken - a national breed of Kazakhstan) sustained mineral fertilizers with rates of $N_{120}P_{90}K_{60}$. In 2016, the field experiments continued on the norms of mineral fertilizer application. The highest density of rice herbage, tillering, and grain yield were visible on the fields with the rice cultivar Tugusken. In 2015, the low rice yield of 31.34–34.5 t/ha was evident, caused by severe soil salinization and insufficient mineral fertilizers. Therefore, in 2016, the following varied doses of mineral fertilizers gained scrutiny for rice on the degraded site: $N_{120}P_{90}K_{60}$, $N_{150}P_{90}K_{60}$, and $N_{180}P_{90}K_{60.}$ Based on the 2016 study results, for rice, the optimal dose of fertilizers $N_{150}P_{90}K_{60}$ performed better, and the increased dose of nitrogen (180 kg) did not considerably enhance the rice grain yield (49.2-47.5 = 1.7 t/ha). With enhanced nitrogen dose, the rice growing season also lengthened, causing the appearance of empty grains in panicles.

Keywords: Rice, degraded soils, soil salinization, mineral fertilizer doses, growth traits, rice productivity

Key findings: Based on the study results in 2016, the identified optimal dose of fertilizers was $N_{150}P_{90}K_{60}$ for better rice productivity. Increasing the nitrogen dose (180 kg) does not significantly increase the rice grain yield. Even with enhanced nitrogen dose, the rice growing season extended and led to the appearance of empty grains in panicles.

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INTRODUCTION

One of the most critical tasks is well-managed rice crop field operations for better production. For crops, the water layer is a temperature regulator, as it performs a vital role in agrotechnical weed control methods and determines the nutrient regimes of the soil (Malakhov *et al*., 2022). Inefficiency in rice field planning could lead to not producing an optimal water layer.

Excessive soil moisture conditions during rice harvesting cause an increase in grain loss, making it practically impossible to separate the threshing methods. Violation of the managed production technology leads to the deformation of the rice field plane, the formation of closed micro-depressions, and the accumulation of moisture in them, rendering field work to have a longer time, and it also harms the soil fertility (Merza *et al*., 2023).

In restoring soil fertility and increasing the rice yield per unit area, applying organic fertilizers previously not regularly applied becomes necessary on various crops (Saltanat *et al*., 2015; Almanova *et al.*, 2023). The impact may also vary depending on the crops, and the temperature effects are more considerable than the precipitation effects (Ybraikozha *et al.*, 2023). Even if fertilizers positively influence crop growth, due to climate change, increased temperatures, and high water demand, crop production may decrease by an average of 57% by 2090 (Mondol *et al*., 2022).

In the Republic of Kazakhstan, rice is an export-oriented crop since neighboring countries traditionally consume a lot of rice for nutrition. The Republic exports about 40,000–45,000 tons of rice. However, there is a scope, and raising further rice production can reach 500,000–600,000 tons annually in Kazakhstan. In achieving that target, the priority task is restoring abandoned degraded lands of the region for rice crop rotation in the coming years (Olzhabayeva *et al*., 2016a).

In Kazakhstan, the deterioration of soil reclamation and environmental conditions may lead to the withdrawal of expensive planned lands from agricultural turnover (Nugmanov *et al.*, 2023). The shortage of irrigation water and the secondary soil salinization are the main factors determining soil fertility levels in rice-growing areas. Therefore, the average rice yield of the Kyzylorda region, Kazakhstan, has decreased from 4.5 t/ha to 3.0–3.2 t/ha. The secondary salinization of the soil has also resulted in a decrease in land productivity of about 21,100 ha (9.4%) of the total utilized area (Olzhabayeva *et al*., 2016b; Olzhabayeva and Rau, 2017). The study aimed to evaluate the effects of mineral fertilizers on the grain yield of two rice cultivars in the Kyzylorda region, Kazakhstan.

MATERIALS AND METHODS

Experimental site and procedure

The presented study's main research object was the rice systems of the Kazakh Scientific Research Institute of Rice Growing (named after Ibray Zhakhayev - KazNII of Rice Growing), located in the central irrigated zone of the Kyzylorda region, Kazakhstan. In the said area, water scarcity is an upsurge of water consumption by various crops and deterioration of soil productivity due to less water availability in these irrigated areas.

The Karaultyubinsk Experimental Farm lies in the central irrigated zone of the Kyzylorda region, Kazakhstan, where loamy and clay soils mainly abound. In the heavy mechanical composition of the soils, the loams and clays predominate along the soil profile to a depth of 1.2 m. The fine-grained sand represents the aquifer horizon, which lay at a depth of more than 2.5 m. Groundwater is in constant pressure up to 0.5 m. Characteristics of the upper meter layer are relatively favorable water-physical properties for irrigation, i.e., with average density (1.35 to 1.40 g/cm^3) and a total porosity (46%). Soil water permeability is median, and from the soil surface, the complete water absorption in the first hour of irrigation is about 60 mm.

On the highly saline lands of the experimental site, soils with heavy mechanical composition have low water permeability, equaling 0.012 m/day. Materials from the Kyzylorda weather station aided climatic characteristics. The average annual air temperature was 9.9 °C, while the frost-free period lasts about 177 days in the region (Olzhabaeva and Rau, 2016).

The soil profile layering varied with the filtration properties of the soil layer in the vertical and horizontal directions and strongly affected the drain spacing. Rehabilitating these reclaimed soils, accounting, and considering the filtration properties of the agricultural landscape's soil strata and the irrigated territories' hydrogeological conditions were insufficient during the drainage construction. The close occurrence of mineralized groundwater levels is regular, including their specific pressure-ascending characters for these territories. Under these conditions, from the groundwater, the ascending capillary waters serve as a permanent supplier of salts to the soil's surface layer.

During the 2015–2016 crop season, the recorded precipitation of 230 mm was 152% of the norm (Table 3). The winter turned out to be abnormally warm, and temperature deviation from the norm reached the record level (+6.0 °C). The said months have never been so warm than the past in that region. As a result of the abnormally early development of spring processes and hot weather, in the first 10 days of March, the mechanically heavy rice soils dried out to a moderately moist state, which made it also possible to begin fieldwork. This year, the spring sowing started about one month earlier than the multi-year deadlines. The pace of its implementation was much higher than last year.

For spring fieldwork, the agrometeorological conditions were favorable. Early spring also made it possible to carry out the sowing of suited crops at the optimal time, i.e., in the last week of March. However, one should note that during the sowing work and the emergence of seedlings, unfavorable conditions occurred caused by an unstable temperature regime, with some days, there was a sharp drop in daytime and nighttime air temperatures up to 20 °C. Thus, on March 22, 2016, during the grain swelling phase, the air temperature dropped to -3.8°C, which caused the late emergence of seedlings compared with previous years (Table 1).

In March-September 2016, rainfall was 99.4 mm, 33.4 mm more than the average annual figures. Of this, 78.4 mm fell during the barley-growing season, while 79.6 mm in the rice-growing season. The norm of precipitation in April was 16 mm, while the actual rainfall equaled 41.8 mm (262%) of the norm (Table 2). In 2015, with the constant flooding of rice crops, cultivating two rice cultivars (Anait - a

Table 1. Meteorological characteristics of 2016 conditions.

Month	Crop season 2015–2016					
	Average daily temperature (°C)			Precipitation (mm)		
	Average monthly	Average long-term	Average long-term (+, -)	Per month	Average long-term	Average long-term (+, -)
September	19.1	18.6	+0.5	1	4	-3.0
October	9.3	10.2	-0.9	14	10	+4.0
November	3.0	1.9	+1.1	29	17	+12.0
Autumn	*10.5*	*10.2*	*+0.3*	*44*	*31*	*13*
December	0.6	-4.7	+5.3 (record)	39	17	+22
January	-1.0	- 6,8	+5.8 (record)	33	19	+14
February	1.9	-5.0	+6.9 (record)	2	15	-13
Winter	*0.5*	*-5.5*	*+6.0 (record)*	*74*	*51*	*+23*
March	9.3	2.7	+6.6	20	17	+3.0
April	14.8	13.3	+1.5	47	16	+31
May	21.3	20.3	+1.0	27	16	+11
Spring	*15.1*	*12.1*	*+3.0*	*94*	*49*	*+45*
June	26.5	26.1	+0.4	18	10	+8.0
July	29.4	27.8	+1.6	0	6	-6
Summer	*27.9*	*26.5*	*+1.4*	*18*	*16*	*+2*
Crop season	13.5	10.8	+2.7	230	151	+79

Table 2. Agroclimatic indicators recorded by the automated weather station, (Demonstration site of KazNII of Rice Growing), 2016.

Month	Air temperature (°C)		Crop season 2016					
			Average daily temperature (°C)			Precipitation (mm)		
	Max.	Min.	Average monthly	Average long-term	Average long-term (+, -)	Per month	Average long-term	Average long-term (+,-)
March	+27.8	-3.8	10.1	2.7	+7.4	19.8	17	+2.8
April	+32.2	+1.1	15.7	13.3	+2.4	41.8	16	+25
May	+38.6	+9.6	22.15	20.3	+1.85	24.0	16	+8
June	+40.3	+15.2	27.1	26.1	++1,0	12.6	10	+2.6
July	+42	+18.4	28.9	27.8	+1.1	1.2	6	-4.8
August	+40.3	+14.6	27.9	24.5	+3.4 (record)	0	3	-3.0
September	+36.9	+7.9	20.6	18.6	+2.0	0	4	-4.0

Table 3. Biological yield of Anait rice.

Sheaf analysis indicators	Sheaf number									Average
	1	2	3	4	5	6	7	8	9	
Plant height (cm)	78	84	85	85	103	95	90	91	104	91
Plants per m^2	85	79	85	85	87	88	78	82	85	84
Productive stems (#)	117	115	118	120	118	116	112	118	121	117
Main panicle length (cm)	17	15	15	17	21	19	19	16	18	17
Grain weight main-panicle^{-1} (g)	2.58	2.78	2.55	2.5	2.83	2.81	2.78	2.68	2.63	2.68
Total weight (g)	9.10	10.15	9.20	10.0	10.86	11.45	10.26	10.54	10.4	10.22
Grains panicle^{-1}(#)	72	70	89	90	85	79	82	89	87	83
1000-grain weight (g)	31.0	30.5	31.3	31.35	31.0	31.25	30.2	31.50	31.10	31.02
Biological yield (t/ha)	30.20	31.97	30.09	30.0	33.39	32.60	31.14	31.59	31.82	31.4

Russian breed, and Tugusken - a national breed of Kazakhstan) attained application with mineral fertilizers at the rate of $N_{120}P_{90}K_{60}$. In 2016, field experiments continued on the degraded sites with the following norms of mineral fertilizers: $N_{120}P_{90}K_{60}$, $N_{150}P_{90}K_{60}$, and $N_{180}P_{90}K_{60}$. At the experimental site, the sowing of rice cultivars, Tugusken and Anait, proceeded at a rate of 250 kg/ha. Flooding of rice fields transpired on May 2, 2015, with a water layer of 10–12 cm.

The month of April 2016, namely, the tillering and stem elongation period, was humid, with an actual precipitation rate of 47 mm and an average annual indicator of 16 mm (more than two precipitation rates), which positively affected the formation of generative organs in crop plants. Beginning summer, the drought also adversely influenced crop growth and development. Thus, in the last weeks of June and July appeared an atmospheric drought, which hurt the grain filling, particularly in early-ripening genotypes. Generally, the moistened period from the beginning of sowing to the earing phase contributed to the lengthening of the growing season of spring grain crops by 7–15 days compared with previous years.

Data analysis

The density of rice herbage computation followed the method developed by Dospekhov (1985). In determining the rice grain yield at the experimental site, the rice germination density, the number of rice plants in one-meter square, and the tilling capacity also incurred calculations as follows:

$$X = \frac{Y(100 - B)(100 - C)}{(100 - B_1)100} \quad (1)$$

Where:
X is the yield at 14% humidity (c from 1 ha), Y is the yield without correction for humidity (c from 1 ha), B is the grain humidity during weighing (%), B_1 is the standard humidity (%), and C is the grain dockage (%).

In the experiment, the average herbage density determination used the following formula:

$$Y = \frac{AP}{P - 1/2H} \quad (2)$$

Where:
A is the actual harvest from the rice plot, P is the estimated number of plants on the plot, and H is the number of missing plants.

RESULTS

In the rice experimental plots, the average biological yield of the rice cultivar Anait was 31.4 t/ha, while for rice plots with cultivar Tugusken, the grain yield was 34.5 t/ha (Tables 3 and 4). The highest density of rice herbage, tillering capacity, and grain yield were evident in the rice plots of cultivar Tugusken. However, the low rice yield of 31.34–34.5 t/ha resulted from severe soil salinization and an insufficient mineral fertilizer dose. These results indicate that rice cultivars Anait and Tugusken exhibited some variability in individual plant characteristics. However, the overall yield for both cultivars remained relatively stable across different conditions and sheaf numbers.

The study further revealed that the influence of nitrogen fertilizers was more prominent at a low seeding rate of three million germinating seeds per hectare. According to the crop structure's various complex indicators, the highest productivity manifested at doses of $N_{150}P_{90}K_{60}$, giving a biological yield of 47.5 t/ha (more than in the first year of development when it equaled 34.5 t/ha). This finding suggests optimizing the nitrogen fertilization strategy can substantially enhance rice yields. Increased nitrogen dose to 180 kg did not considerably boost the grain yield (49.2-47.5 = 1.7 t/ha). Besides, with this nitrogen dose, the growing season of rice also extended, causing empty grains in panicles.

Also noteworthy was the higher nitrogen dose application nonsignificantly increased grain yield and extended the growing season. This extension had unintended consequences, including empty grains in panicles. This observation underscores the importance of balancing yield goals with grain quality, as a longer growing season may not necessarily translate to higher overall productivity if compromising grain quality.

Table 4. Biological yield of Tugusken rice.

Sheaf analysis indicators	Sheaf number									Average
	1	2	3	4	5	6	7	8	9	
1	2	3	4	5	6	7	8	9	10	11
Plant height (cm)	97	95	88	96	103	98	97	114	103	99
Plants per m^2	90	95	92	89	92	98	94	92	96	93
Productive stems (#)	125	122	128	122	124	128	128	126	126	125
Main panicle length (cm)	19	17	15	16	18	17	18	18	19	17
Grain weight main-panicle^{-1}(g)	2.75	2.68	2.78	2.69	2.72	2.76	2.80	2.76	2.78	2.75
Total weight (g)	10.22	9.82	10.40	10.0	10.15	10.35	10.52	10.34	10.40	10.24
Grains panicle^{-1}(#)	99	88	92	95	98	90	98	98	96	95
1000-grain weight (g)	32.0	31.95	32.30	31.0	31.99	32.32	32.40	32.30	32.28	32.06
Biological yield (t/ha)	35.63	32.70	35.54	32.28	33.73	35.33	35.80	34.78	34.95	34.5

DISCUSSION

The quality of irrigation water and the salt composition also affect the fractional composition of humus and the microbiological and biochemical processes. However, the prevalence of sodium and magnesium in irrigation water causes the opposite effects, i.e., changes in the water/physical and filtration soil properties (Turdaliev *et al*., 2022). The enhanced efficiency of mineral fertilizers is one of the principal factors increasing the rice crop yield (Zhang *et al*., 2018; Yulita *et al*., 2021).

In the applicable study, the low rice yield during the crop season 2015 amounted to 31.34–34.5 t/ha due to severe soil salinization and insufficient mineral fertilizer doses. Therefore, during the crop season 2016, the following doses of mineral fertilizers applied on the rice crop bore scrutiny: $N_{120}P_{90}K_{60}$, $N_{150}P_{90}K_{60}$, and $N_{180}P_{90}K_{60}$. The studies showed that by providing the best nutritional regime of the soil, mineral fertilizers develop favorable conditions for the growth and development of the rice crop (Suraganova *et al*., 2022). With recommended increased doses of fertilizers, the rice grain attained significant enhancement (Wang *et al*., 2018).

The presented research further enunciated that the influence of nitrogen fertilizers was more distinct at a low seeding rate of three million germinating seeds per hectare. According to the crop structure indicators, the highest productivity was apparent at doses of $N_{150}P_{90}K_{60,}$ where the biological yield was 47.5 t/ha. It was higher than in the first year of development (34.5 t/ha). However, an increased nitrogen dose (180 kg) did not substantially raise the rice grain yield (49.2-47.5 = 1.7 t/ha). Besides, the boost in nitrogen dose also extended the rice-growing season, causing the appearance of empty grains in the panicles.

Comparing findings with existing studies in rice productivity and nitrogen fertilizer application provides valuable insights into the broader context of sustainable rice cultivation. Several studies have investigated the impact of nitrogen fertilizers on rice yields, and our results aligned with some key trends while offering unique perspectives. Dhakal *et al*. (2021) have also highlighted that optimized fertilizer doses can significantly enhance crop yields. This study reiterated this point, showcasing the potential for improving rice production in regions with similar soil and climate conditions.

For developing rice farming, it is necessary to improve agrotechnology related to the use of various mineral and organic fertilizers (Kongpun and Prom-u-Thai, 2021), plant protection measures against weeds, insects, and diseases (Mukhamadiyev *et al*., 2023), rationally maintaining the water regime in rice fields (Sreethong *et al.*, 2019; Kalashnikov *et al*., 2022), forming biologized crop rotations with the selection of various rice cultivars, and the inclusion of upland crops and mandatory planning by a laser planner (Shaimerdenova *et al*., 2023).

CONCLUSIONS

The results, based on the study of two rice cultivars (Anait and Tugusken) with mineral fertilizers of $N_{120}P_{90}K_{60}$ in 2015, showed the maximum density of rice herbage, tillering, and grain yield, evident in the fields grown with rice cultivar Tugusken. The low rice yield (31.34–34.5 t/ha) was due to soil salinization and the insufficient dose of mineral fertilizers. According to the study carried out in 2016 for rice crops, the optimal dose of fertilizers was $N_{150}P_{90}K_{60,}$ performing better. The increased nitrogen dose (180 kg) had a nonsignificant effect on the rice grain yield (49.2-47.5 = 1.7 t/ha) and extended the growing season, causing the appearance of empty grains in the rice plant panicles.

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